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Optimization of Deposition Rate of Weld Bead for Gas arc welding of Stainless Steel (SS316) using Taguchi Methods

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Abstract - **TIG welding is one of the most widely used welding technique due to its versatility and ease that makes it suitable in almost any kind of working condition. Stainless Steel (SS316) possessing high strength and toughness is usually known to create major challenges during its welding. TIG welding is suitable for Stainless Steel (SS316) with good weld ability and production economy. In this study, Taguchi's Design of Experiment approach is used to study the effect of welding process parameters on deposition rate of weld bead. Three input parameters Current, gas flow rate and no. of passes are selected to ascertain their effects on the deposition rate of weld bead. In this experiment the three different levels of current, gas flow rate and number of passes have been chosen. The parameters are analyzed at three different levels. The values of current are 110 A, 130 A and 150 A. Gas flow rates are selected as 4(lit/m), 8 and 12 and number of passes as 1, 2 and 3. The choice and the selection of the parameters are decided by considering the objective of present study.**

Keywords: Taguchi Methods, TIG Welding, Design of Experiment, Deposition Rate.

1. INTRODUCTION

Tungsten inert gas (TIG) welding is an arc-welding process that produces coalescence of metals by heating them with an arc between a non-consumable tungsten electrode and the base metal. This process was originally developed for hard-to-weld lightweight metals such as aluminum, magnesium and titanium. Many delicate components in aircraft and nuclear reactors are TIG welded and therefore TIG weld quality is of extreme importance. Basically, TIG weld quality is strongly characterized by the weld pool geometry; this is because the weld pool geometry plays an important role in determining the mechanical properties of the weld (1) (2). TIG weld quality is strongly characterized by the weld pool geometry. This is because the weld pool geometry plays an important role in determining the mechanical properties of the weld (4).

2. LITERATURE REVIEW

K.Shanmugam,A.K.Lakshminarayanan,V.Balasubramanian[2008] Explain effect of filler metals such as austenitic stainless steel, ferrite stainless steel and duplex stainless steel on fatigue crack growth behavior of the gas tungsten arc welded ferrite stainless steel joints was investigated. Sedat Kolukisa[2009] explains the effect of welding temperature on the weld ability in diffusion welding of martensitic (AISI 420), stainless steel with ductile (spheroidal graphite-nodular) cast iron was investigated. Her-Yueh Huang[2009] describe the effect of each welding parameter on the weld bead geometry, and then sets out to determine the optimal process parameters using the Taguchi method to determine the parameters. Lenin N., Sivakumar M. and Vigneshkumar D [2010] did optimization of welding input process parameters for obtaining greater weld strength in the manual metal arc (MMA) welding of dissimilar metals like stainless steel and carbon steel is presented. Honarbakhsh-Raouf and H.R. Ghazvinloo[2010] focuses on the effect of FCAW-G process parameters on the hardness and microstructure of weld in RQT 701-British steel having 5 mm thickness. Her-Yueh Huang[2009] describe the effect of each welding parameter on the weld bead geometry, and then sets out to determine the optimal process parameters using the Taguchi method to determine the parameters. Lenin N., Sivakumar M. and Vigneshkumar D [2010] did optimization of welding input process parameters for obtaining greater weld strength in the manual metal arc (MMA) welding of dissimilar metals like stainless steel and carbon steel is presented. Honarbakhsh-Raouf and H.R. Ghazvinloo[2010] focuses on the effect of FCAW-G process parameters on the hardness and microstructure of weld in RQT 701-British steel having 5 mm thickness. Bayram Kocabekir, Ramazan Kac¸ar, Su leyman Gu ndu z & Fatih Hayat[2008] investigates the effect of weld time, different weld atmospheres and weld cooling conditions on the resistance spot weld quality of 316L stainless steel.

2.1 Material, processing and Welding Machine

Material

The material used in this study was stainless steel (SS 316). The composition of the base material and filler material is shown in table 2.1 and 2.2 respectively (6). The following table shows the composition of base metal and welding electrode.

Stainless steel	Cr	Ni	C	Mn	Si	P	S	N	M_O
Type 304	16-18	10-12	0.08	2.00	0.75	0.045	0.030	0.10	2-3

Table 2.1. Chemical Composition of Base Metal (SS 316)

C	Mn	P	S	Fe
0.14	0.5-0.8	0.040 max	0.050 max	98.72-99.97

Table 2.2: Chemical Composition of filler Metal

Metal Deposition Rate Calculation:

The metal deposition rate of a welding consumable (electrode, wire or rod) is the rate at which weld metal is deposited (melted) onto a metal surface. Metal deposition rate is expressed in kilogram per hour (kg/hr). Metal deposition rate is based on continuous operation, not allowing for stops and starts such as, electrode change over, chipping slag, cleaning spatter, machine adjustment or other reasons. When welding current is increased so does the metal deposition rate. When electrical stick out is increased in the case of GTAW the metal deposition rate will also increase.

Deposition Rate = (0.184kg – 0.182kg) / 0.006269hr = 0.319kg/hr Deposition rate is calculated by doing actual welding test, and the following shows the formula for measuring deposition rates.

Example:-

M.D.R. = --

Measured period of time

Plate after welding: 0.184kg

Plate before welding:

Weight of test plate after welding – Weight of test plate before welding

Welding time = 22.57 sec. = (22.57/3600) hr = 0.006269hr

Welding machine : Semiautomatic GTAW equipment with direct current electrode negative (DCEN), power source with a capacity of 300 A was used to join the stainless steel plates (SS316) of size 50mm ×40mm ×5mm. The rated output current range is 10-300 A and rated output voltage is 22 V. frequency of the machine is 50/60 Hz and duty cycle is 60%. Efficiency is 85% and power factor is 0.93.

3. ADOPTED METHODOLOGY

In the traditional one-variable-at-a-time approach, only one variable at a time is evaluated keeping remaining variables constant during a test run. This type of experimentation reveals the effect of the chosen variable on the response under certain set of conditions. The major disadvantage of this approach is that it does not show what would happen if the other variables are also changing simultaneously. This method does not allow studying the effect of the interaction between the variables on the response characteristic.

3.1 The Taguchi Approach

Design of Experiments (DOE) is a powerful statistical technique introduced by R. A. Fisher in England in the 1920's to study the effect of multiple variables simultaneously [Goyal et al., 2014; Sharma et al., 2014; Kumari et al., 2013]. In his early applications, Fisher wanted to find out how much rain, water, fertilizer, sunshine, etc. are needed to produce the best crop. Since that time, much development of the technique has taken place in the academic environment. As a researcher in Electronic Control Laboratory in Japan, Dr. Genechi Taguchi carried out significant research with DOE techniques in the late 1940's. He spent considerable effort to make this experimental technique more user-friendly and applied it to improve the quality of manufactured products. Dr. Taguchi's standardized version of DOE, popularly known as the Taguchi methods or Taguchi approach, was introduced in the USA in the early 1980's (5).

3.2 Steps involved in DOE Approach

Dr. Genechi Taguchi has standardized the methods for each of these DOE application steps described below. Thus, DOE using the Taguchi approach has become a much more attractive tool to practicing engineers and scientists (7).

- **Experiment planning and problem formulation -** Experiment planning guidelines are consistent with modern work disciplines of working as teams. Consensus decisions about experimental objectives and factors make the projects more successful.

- **Experiment layout -** High emphasis is put on cost and size of experiments. Size of the experiment for a given number of factors and levels is standardized. Approach and priority for column assignments are established. Clear guidelines are available to deal with factors and interactions (interaction tables). Uncontrollable factors are formally treated to reduce variation. Discrete prescriptions for setting up test conditions under uncontrollable factors are described. Guidelines for carrying out the experiments and number of samples to be tested are defined.

- **Data analysis -** Steps for analysis are standardized (main effect, ANOVA and Optimum). Standard practice for determination of the optimum is recommended. Guidelines for test of significance and pooling are defined.

Overall advantage - DOE using Taguchi approach attempts to improve quality which is defined as the consistency of performance. Consistency is achieved when variation is reduced. This can be done by moving the mean performance to the target as well as by reducing variations around the target. The prime motivation behind the Taguchi experiment design technique is to achieve reduced variation (also known as robust design). This technique, therefore, is focused to attain the desired quality objectives in all steps. The classical DOE does not specifically address quality.

3.3 Optimization Problem: Taguchi method treats optimization problems in following two categories.

- Static problems
- Dynamic problems

Static Problems

Generally, a process to be optimized has several control factors which directly decide the target or desired value of the output. The optimization then involves determining the best control factor levels so that the output is at the target value. Such a problem is called as a "static problem". This is best explained using a P-Diagram which is shown below ("P" stands for Process or Product). Noise is shown to be present in the process but should have no effect on the output! This is the primary aim of the Taguchi experiments to minimize variations in output even though noise is present in the process. The process is then said to have become robust.

(I) Smaller-The-Better:

$$n = -10 \, Log_{10} \, [\text{mean of sum of squares of measured data}] \quad (1)$$

This is usually the chosen S/N ratio for all undesirable characteristics like “defects” etc.

(II) Larger-The-Better:

$$n = -10 \, Log_{10} \, [\text{mean of sum of squares of reciprocal of measured data}] \quad (2)$$

This case has been converted to smaller-the-better by taking the reciprocals of measured data and then taking the S/N ratio as in the smaller-the-better case.

(III) Nominal-The-Best:

$$n = -10\,Log_{10}\,[\text{Mean squared deviation}] \quad (3)$$

this case arises when a specified value is most desired, meaning that neither a smaller nor a larger value is desirable.

Dynamic Problems: If the product to be optimized has a signal input that directly decides the output, the optimization involves determining the best control factor levels so that the "input signal / output" ratio is closest to the desired relationship. Such a problem is called as a "dynamic problem". This is best explained by a P-Diagram which is shown below. Again, the primary aim of the Taguchi experiments—to minimize variations in output even though noise is present in the process—is achieved by getting improved linearity in the input/output relationship.

4. RESULTS AND DISCUSSION

A large number of experiments have been performed by taking various parameters in consideration and some of them are considered as main parameters.

4.1 Main Effects due to Parameters

The main effects can be studied by the level average response analysis of mean data and S/N ratio. The analysis is done by averaging the mean and S/N data at each level of each parameter and plotting the graph. The level average response from the mean data helps in analyzing the trend of performance characteristic with respect to variation of the factors under study. Tables4.2 and 4.3 report the factor effect on mean and S/N ratio respectively. The main effects have been plotted as shown in Fig.5.1.

Exp. No.	**Deposition Rate**	**Deposition Rate Mean Value**	**Deposition Rate S/N Ratio**
1	0.320	0.320	-9.8970
2	0.180	0.180	-14.8945
3	0.186	0.186	-14.6097
4	0.232	0.232	-12.6902
5	0.182	0.182	-14.7986
6	0.362	0.362	-8.8258
7	0.274	0.274	-11.2450
8	0.403	0.403	-7.8939
9	0.336	0.336	-9.4732
Average		0.275	-11.6219

Table 4.1: Experimental Data for Metal Deposition Rate

FACTOR	**LEVELS**	**METAL DEPOSITION RATE**
CURRENT	A_1	0.2287
	A_2	0.2587
	A_3	0.3377
GAS FLOW RATE	B_1	0.2753
	B_2	0.2550
	B_3	0.2947
NO. OF PASSES	C_1	0.3617
	C_2	0.2493
	C_3	0.2140

Table 4.2: Factor Effect on Average Response

FACTOR	**LEVELS**	**METAL DEPOSITION RATE**
CURRENT	**A_1**	**-13.134**
	A_2	**-12.105**
	A_3	**-9.537**

GAS FLOW RATE	**B_1**	**-11.277**
	B_2	**-12.529**
	B_3	**-10.970**
NO. OF PASSES	**C_1**	**-8.872**
	C_2	**-12.353**
	C_3	**-13.557**

Table 4.3: Factor Effect on S/N Ratio

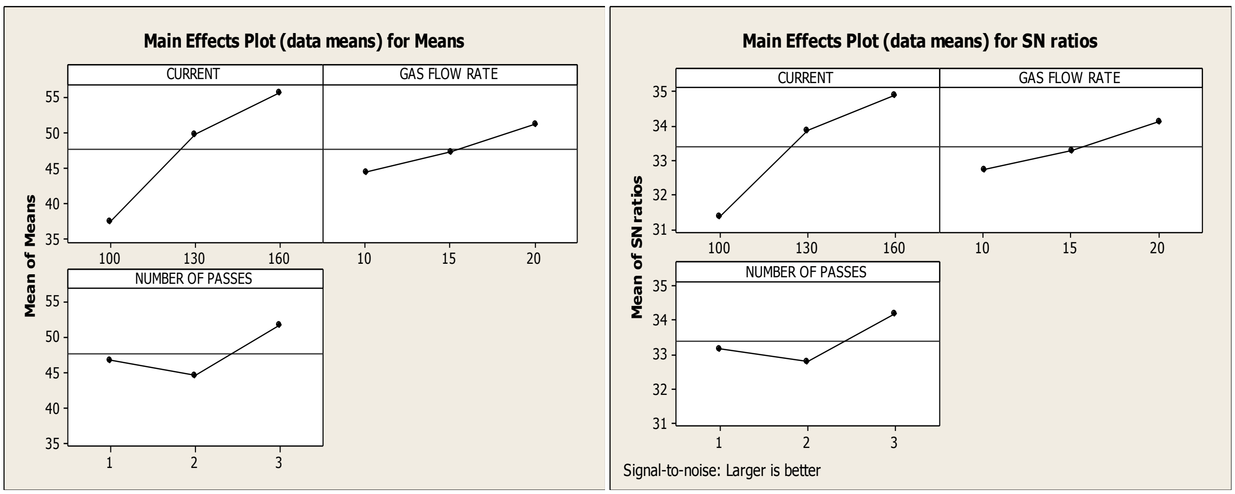

Fig.5.1 Effect of Process Parameters on Hardness (Raw data and S/N Ratio)

4.2 Analysis of Variance (ANOVA)

Analysis of variance is a statistical method used to interpret experimental data and make the necessary decision. ANOVA is statistically based decision tool for detecting any difference in average performance of group of items tested. The ANOVA (general linear model) for mean has been performed to identify the significant parameters to quantify their effect on performance characteristic. The ANOVA for raw data is given below in Table 4.4.

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**	**Percentage contribution**
Current	2	0.0190220	0.0190220	0.0095110	214.3	0.005	35.13
Gas flow rate	2	0.0023607	0.0023607	0.0011803	26.62	0.036	4.63
No. of passes	2	0.0356727	0.0356727	0.0178363	402.32	0.002	65.88
Error	2	0.0000887	0.0000887	0.0000443			0.1638
Total	8	0.0541440					
S = 0.00665833 R-Sq = 99.84% R-Sq(adj) = 99.38% Order of significance 1: No. of passes; 2: Current; 3: Gas flow rate;							

Table 4.4: ANOVA Summary for Metal Deposition Rate (Raw Data)

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage contribution
Current	2	20.585	20.585	10.292	106.62	0.009	34.13
Gas flow rate	2	4.093	4.093	2.047	21.20	0.045	6.786
No. of passes	2	35.441	35.441	17.721	183.57	0.005	58.76
Error	2	0.193	0.193	0.097			0.32
Total	8	60.312					

S = 0.310696 R-Sq = 99.68% R-Sq(adj) = 98.72%
Order of significance 1: No. of passes; 2: Current; 3: Gas flow rate;

Table 4.5: S/N ANOVA for Metal Deposition Rate

4.3 DISCUSSION

It can be seen from the above order of significance that no. of passes is the most significant factor that is affecting the metal deposition rate. The different input parameters used in experimentation can be ranked in the order of increasing effect as Gas flow rate, Current and No. of passes. From the Figure 4.1 it can be revealed that the optimal parameter setting is $A_3B_3C_1$. In this study we conclude that the optimal input parameters setting for current is 150 amp, gas flow rate 12L/min and no. of passes 1 during the welding of stainless steel (SS316) on TIG welding machine as far as the metal deposition rate is concerned. It is revealed from the ANOVAs (raw data & S/N data) that all the three parameters are significant in both ANOVAs, hence these parameters affect both the mean value and variation around the mean of metal deposition rate.

5. CONCLUSIONS

The following conclusions have been drawn from the study:

1. The percent contribution of no. of passes (63.43%) in affecting metal deposition rate is fond maximum followed by current (33.84%) and gas flow rate (20.61%).
2. The analysis reveals $\mathbf{A_3B_3C_1}$ as the optimal input parameters setting for optimizing the metal deposition rate A3**=140 amp B3=15L/min C1=1** A-Current, B-Gas flow rate, C-no. of passes
3. The optimized value of metal deposition rate is **0.434 kg/hr**. The optimized value for metal deposition rate has been validated through the confirmation experiments.

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